

# GEOSIERRA'S PATENTED TRENCHLESS CONSTRUCTION METHOD FOR PLACING DEEP PRB WALLS

**Grant Hocking**  
GeoSierra LLC

3730 Chamblee Tucker Road, Atlanta, GA 30341  
Phone: (678) 406-0094, Email: ghocking@geosierra.com

## **INTRODUCTION**

Zero valent iron permeable reactive barriers (PRBs) remediate chlorinated solvent contaminated groundwater by abiotic degradation of the halogenated volatile organic compounds into harmless daughter products and the reduction and precipitation of metals, such as hexavalent chromium. Earlier means of installing such reactive barriers was in a funnel and gate configuration; however, in the past five (5) years the PRBs have been installed as continuous permeable barriers either by trenching, slurry wall, or azimuth controlled vertical hydraulic fracturing technology. Vertical Hydrofracturing has been used at three Superfund sites in New Jersey, Iowa and Virginia and at two Fortune 100 corporation sites in California. Three of these Vertical Hydrofracturing PRB installations exceed 100 feet below ground surface and the longest is 1200 feet in length. This paper describes the vertical hydrofracturing technology and the Quality Assurance/Quality Control procedures to assist design and provide assurance that the PRB is constructed as planned. Activities described are: (1) Pre-installation site characterization, (2) Testing and design, (3) Real-time monitoring during the PRB installation by the active resistivity imaging method, and (4) Post-installation tests confirming the wall thickness and permeability. Full scale PRB remediation case studies are used to highlight the advantages and benefits of PRB construction by vertical hydrofracturing.

## **PRB INVESTIGATION & PROBABILISTIC DESIGN METHODOLOGY**

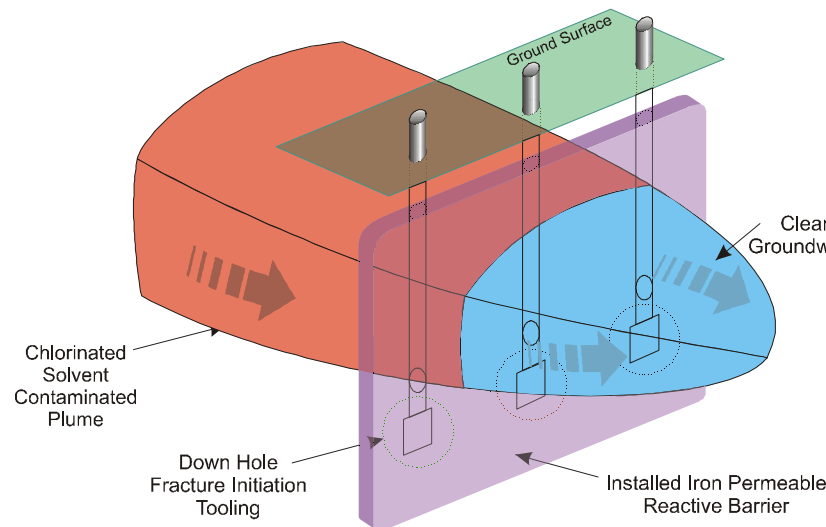
Design input parameters required for iron PRB design are: formation hydraulic conductivity, groundwater flow hydraulic gradient, VOCs concentrations, VOCs degradation half lives, iron PRB porosity and iron PRB effective thickness. Laboratory column tests utilizing site groundwater quantify the degradation reaction rates and pathways (daughter products) of the particular contaminant specie in the presence of iron filings, and also address additional issues such as potential precipitation and clogging of the PRB. Formation hydraulic conductivity data are quantified in situ, either from pumping tests or utilizing the hydraulic pulse interference test described later in the QA/QC Verification Procedures section.

Deterministic design procedures, while adequate for feasibility evaluation, are not sufficient for final iron PRB design because the factors of safety from past practices are not available for such systems. Probabilistic methods, on the other hand, can accommodate variability in parameter data and are ideally suited for system design such as an iron PRB. The probabilistic method enables quantification of the degree of confidence that contaminant effluent concentrations will not be exceeded. Probabilistic analyses quantify the impact of parameter variability on overall system performance and thus rank the parameter by sensitivity. The PRB probabilistic design methodology incorporates the degradation of VOCs by the PRB and the impact of natural attenuation mechanisms active downgradient of the PRB. The iron PRB is designed to treat influent VOC concentrations to meet target VOC concentrations at a pre-determined downgradient Site Compliance Point (SCP). The methodology incorporates a probabilistic multi-specie VOC degradation model for degradation within the PRB and a probabilistic fate and transport model for VOC natural attenuation downgradient of the PRB.

## **VERTICAL HYDROFRACTURING & PRB CONSTRUCTION**

Vertical Hydrofracturing enables placement of PRBs far deeper than possible by conventional construction methods. Continuous PRB treatment walls as deep as 300 ft and up to 9 inches thick can be injected into the subsurface using Vertical Hydrofracturing. This installation method is minimally invasive; requiring only the drilling of 6-inch boreholes every 15 feet on the planned placement line of the PRB, see Figure 1. Specialized tooling is inserted into the borehole to the required depth and oriented to control the direction and fracture pathway for what will become the PRB wall. The vertical interval for fracturing and injection is then isolated in the borehole by packers. Iron filings of medium sand size are mixed with a hydroxypropylguar (HPG) biodegradable slurry. Immediately before injection a special breaker enzyme is included in the slurry mixture, which is then cross-linked to form a highly viscous gel containing ~10 lbs of iron filings per gallon. This highly viscous iron filings carrier is then injected under low pressure through the down-hole tooling to propagate the fracture and form the PRB wall. The gel carrier follows the fracture pathway causing the soil to separate, creating the iron treatment zone. The enzyme breaks the gel within an hour or two, reducing it to water and harmless sugars, leaving a clean wall of

iron filings. The wall is built from the bottom up by coalescing injections from each borehole to form a continuous PRB (i.e. a continuous vertical wall of iron filings).

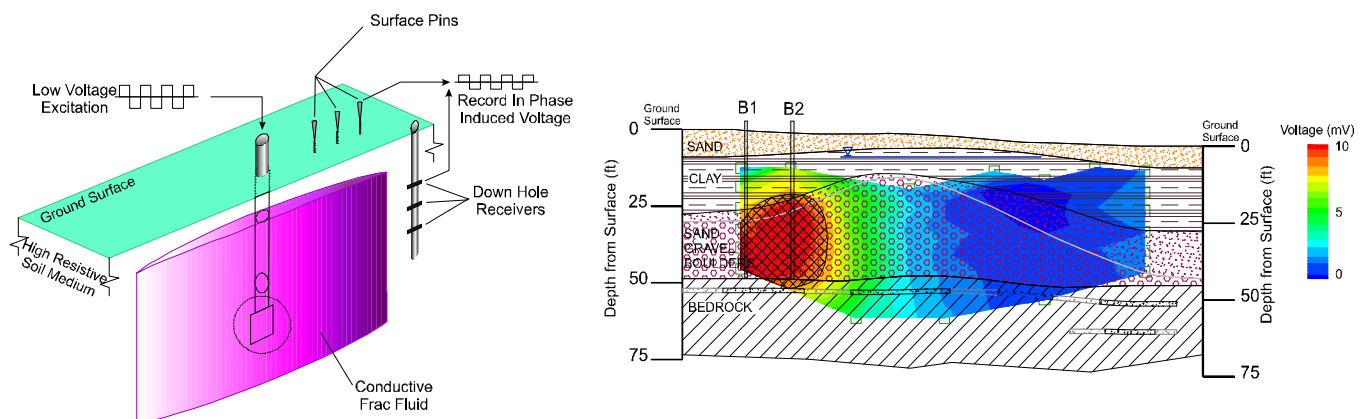


**FIGURE 1. Iron PRB Installed by Vertical Hydrofracturing and Injection**

## GEOSIERRA'S SUITE OF QA/QC TOOLS AND VERIFICATION PROCEDURES

### Active Resistivity Imaging to “See” PRB Construction in Real-Time

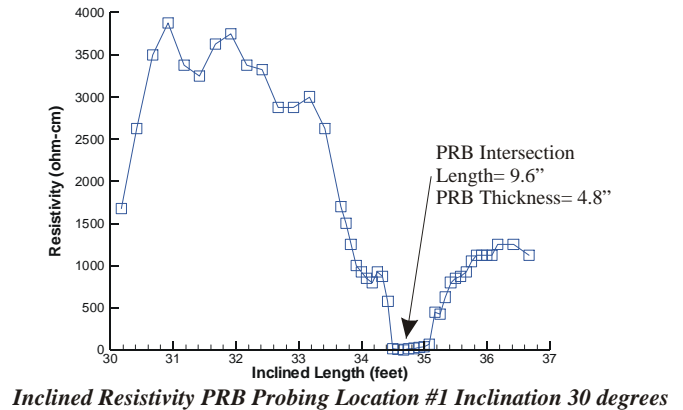
The PRB is constructed by the injection of the iron filings into the pre-installed frac casings with real time quality assurance monitoring of the injections to quantify the PRB geometry and iron loading densities. The real time imaging of the PRB geometry during construction involves active resistivity instrumentation equipment and specialized imaging software. During injection, the iron-gel mixture is electrically energized with a low voltage 100 Hz signal. Downhole and surface resistivity receivers are monitored to record the in-phase induced voltage by the propagating fracture. By monitoring the fracture fluid induced voltages and utilizing an incremental inverse integral model, the fracture fluid geometry is quantified and displayed during the installation process, see Figure 2.



**FIGURE 2. Real Time Active Resistivity Imaging of PRB Construction.**

### Inclined Profiling to Verify PRB Thickness

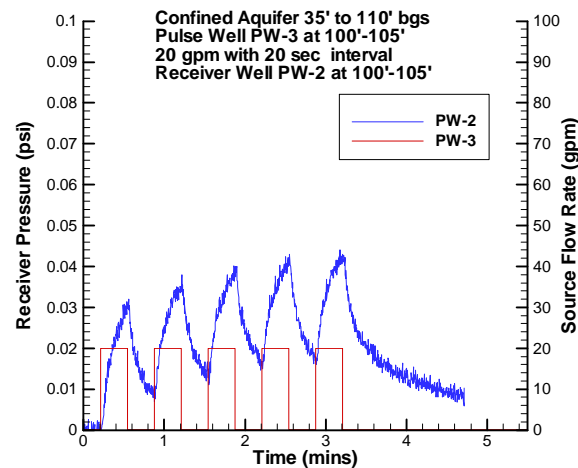
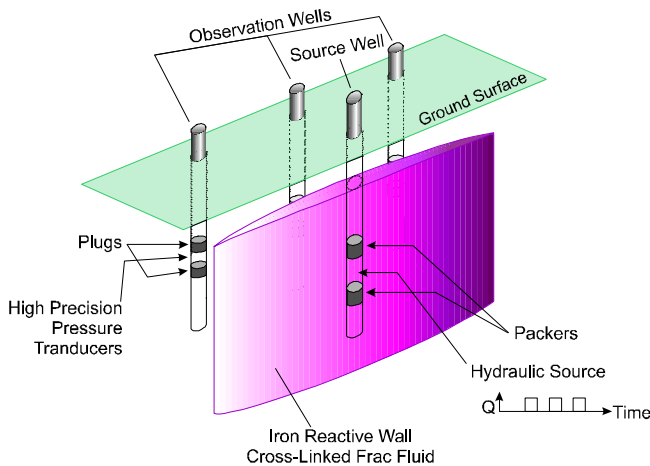
Verification procedures of the in situ constructed geometry of the PRB and the impact of the PRB construction on groundwater flow regimes are necessary for a high confidence in the quality control/quality assurance of the constructed PRB. Difficulties in direct sampling of iron PRBs have led to the utilization of an inclined direct push soil electrical conductivity/resistivity probe to determine the iron PRB thickness. The electrical resistivity contrast between native soils and the iron PRB is sufficient to clearly identify the iron PRB thickness by inclined probing as shown on Figure 3.



**FIGURE 3. Iron PRB Thickness Profiling by Inclined Soil Resistivity Probe.**

### Hydraulic Pulse Interference to Verify the Finished PRB Does Not Impact Permeability

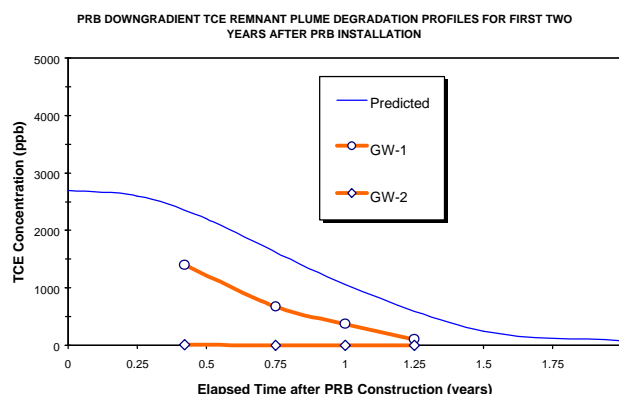
PRB systems need to be constructed to ensure the barrier's permeability does not impede or modify the groundwater flow regimes. Since any impediment to flow by a PRB system can have serious consequences on overall system performance, it is imperative to conduct hydraulic integrity testing of such a system to ensure it is constructed as planned. The hydraulic pulse interference test is conducted across the PRB's alignment prior and after construction to quantify the barrier's hydraulic characteristics. These hydraulic pulse interference tests conducted pre and post PRB construction to quantify that the PRB has not affected the permeability and will not impede groundwater flow at the site, as shown on Figure 4.



**FIGURE 4. Hydraulic Pulse Interference Test Across Iron PRB Alignment.**

### GROUNDWATER PERFORMANCE MONITORING

Verification of the iron PRB performance is monitored from sampling groundwater monitoring wells located both upgradient and downgradient of the PRB alignment. PRB influent and effluent groundwater contaminant concentration levels are measured to track the PRB performance and ensure remediation objectives are being met. The groundwater is sampled for a variety of VOCs, metals and other inorganic parameters. Iron PRBs have been installed and monitored in the field for the past ten (10) years, as described in Reynolds et al (2002) and Puls et al (2002). These PRBs are functioning satisfactory with no signs of degradation in performance over time, no signs of biological activity or clogging and with expectations of the PRB performing for at least twenty to thirty years. Groundwater performance monitoring data are presented for iron PRBs constructed by Vertical Hydrofracturing, with data from the McGraw Edison Superfund site in Centerville, IA shown on Figure 5.



**FIGURE 5. McGraw Edison Superfund PRB Groundwater Performance Data.**

## CONCLUSIONS

PRBs are suitable cost effective remedies for remediating contaminated groundwater, both for plume remediation and as source control. Vertical Hydrofracturing is a proven installation procedure for constructing iron PRBs at both shallow and significant depth in a wide variety of geological environments. Real time imagery of the injected geometry of the PRB enable the barrier to be constructed as designed. Construction QA/QC techniques verify the as built geometry of the PRB to be within specification as detailed in the design. Detailed hydraulic pulse interference tests conducted across the PRB alignment, pre and post PRB construction, verifies that the PRB does not impact or impede groundwater flow at the site. Groundwater performance monitoring data quantify the degradation performance of the PRB. Iron PRBs are now considered a proven established technology and have replaced pump and treat remedies in the Records of Decision (RODs) at Superfund sites throughout the US.

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